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Species Composition and Diversity in Mid-altitudinal Moist Temperate Forests of the Western Himalaya

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ABSTRACT : The present study was undertaken in middle altitudinal (1500 to 2500 masl) moist temperate forest of Mandal-Chopta area in the Garhwal region of Uttarakhand, India. The aim of the present study was to assess the variation in species composition and diversity in different vegetation layers viz. herb, shrub and tree, at different altitudes. Shannon-Wiener diversity index ($\overline{H}$), Nha^{-1}, total basal cover per hectare (G), Simpson concentration of dominance, Pielou Equitability, species richness (SR), Margalef index, Menheink index of species richness and β-diversity were calculated to understand community composition. Tree G ranged from 84.25 to 35.08 m^2ha^{-1} and total stem density varied from 990 to 1470 Nha^{-1}. Total SR (herb, shrub and trees) among different forest types ranged between 31 and 58. Maximum G of herb and shrub layers was recorded at lower altitudes between 1500 and 1650 masl. β-diversity was higher in herb layers as compared to tree and shrub layers. Dominance-diversity curves were also drawn to ascertain resource apportionment among various species in different forest types. Values of species diversity, $\overline{H}$, Nha^{-1} and G were higher in the study area as compared to similar forests growing in other parts of Uttarakhand Himalaya.

Keywords : Density, Diversity, Altitude, Beta diversity, Dominance-diversity, Garhwal Himalaya

INTRODUCTION

Forests are the most extensive, complex and biologically productive entities amongst all the terrestrial ecosystems. They are one of the major categories of landscapes, and form one of the most important natural resources of the world. Forests are three-dimensional systems, which can be thought of as both a product of forest dynamics and biophysical processes and as a template for biodiversity and ecosystem function. The species in a community grow together in a particular environment because they have a similar requirement for existence in terms of environmental factors (Ter Braak, 1987). A variety of factors contribute to the diversity of plants. Plant species diversity is affected by several topographic gradients and climatic variations. The factors which affect plant species richness and diversity are of crucial importance in ecology and conservation biology. The number of species in a particular forest type varies markedly along the altitudinal range of its growth, which depends on the complex suit of factors that characterize the habitat of individual species. The physiographic factors are widely known to show a major impact on plant microhabitats, especially in hill-slope form (Sharma et al., 2010a). The physiographic features such as elevation and aspect have a profound influence on the distribution, growth, form and structure of tree species, as a result of which the individual tree species has different values for density and basal cover at various altitudes and aspects (Wikum and Wali, 1974). Slobodkin and Sanders (1969) opined that species richness of any community is a function of severity, variability and predictability of the environment in which it develops. Therefore, diversity tends to increase as the environment becomes more favourable and more predictable (Putman, 1994). Thus it is necessary to understand the dynamics and relationship between various factors which affect richness and diversity of the forests.

Himalayan forests play an important role in tempering the inclemencies of the climate, in cooling and purifying the atmosphere, in protecting the soil, in holding the hill-slopes in position, and in building up huge reserves of soil

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nutrients. Middle altitudinal forests (between 1500 and 2500) of the western Himalaya are considered to be very productive and rich in biodiversity. It has been realized that for the sound management of Himalayan ecosystem, the knowledge of plant community, diversity, population, distribution, regeneration, utilization, environmental impact assessment, etc are essential to support the conservation and restoration of the environment. This type of ecological knowledge is fundamental for conservation and sustainable utilization, and may provide important information to the policy makers for drafting management plans of fragile mountain ecosystems. Although recently some studies have analyzed the phytosociology and diversity of different forest types of the region (Sharma et al., 2009a, 2009b, 2009c, 2010a, 2010b, 2010c, 2010d; Gairola, 2010), but still there is paucity of studies related to middle altitudinal forests of Garhwal Himalaya. Keeping the aforesaid facts in view, the aim of the present study was to assess the variation in species composition and diversity of different vegetation layers *viz*. herb, shrub and tree, in middle altitudinal forest types of moist temperate Mandal-Chopta forest area.

MATERIALS AND METHODS

Study area

The present study was conducted in Mandal-Chopta forest area, which forms a large (nearly 1100 ha), prestigious, and botanically valuable reserve complex (Trishula Reserve Forest of Kedarnath Forest Division) in the Garhwal region (Western Himalaya) of Chamoli district of Uttarakhand state, India (Fig. 1). It occurs at 30° 27.560' N latitude and 79° 15.234' E longitude along an altitudinal gradient of 1500 masl to 2500 masl. It is a rich moist temperate forest situated 12 km away from the district headquarter, Gopeshwar. Recently Gairola et al. (2010) have recorded 338 species of vascular plants (334 Angiosperms and 4 Gymnosperms) belonging to 93 families (91 Angiosperms and 2 Gymnosperms) and 249 genera (246 Angiosperms and 3 Gymnosperms) from the study area. The study area is characterized by undulating topography with gentle slopes on Northern, Northeastern and Northwestern faces and somewhat steep slopes on Southern and Southwestern directions. The soil types found in the region are brown and black forest soils and podozolic soils. Soil texture of the study area is predominantly sandy loam and sandy clay loam whereas soil colour varies from yellowish brown to dark brown (Sharma et al., 2010d). Soils are generally gravelly and large boulders are common in the area. Numerous high ridges, deep gorges and precipitous cliffs, rocky crages and narrow valleys are part of the topography of the region. The topography of the area has also been influenced by landslides, which are common during rainy season. Geologically, the rocks in the study sites are complex mixture of mainly sedimentary, low grade metamorphosed with sequence capped by crystalline nappe. The study area

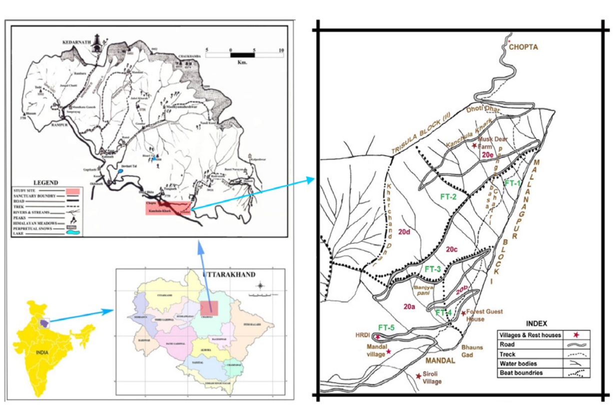

Fig. 1. Map of the study area

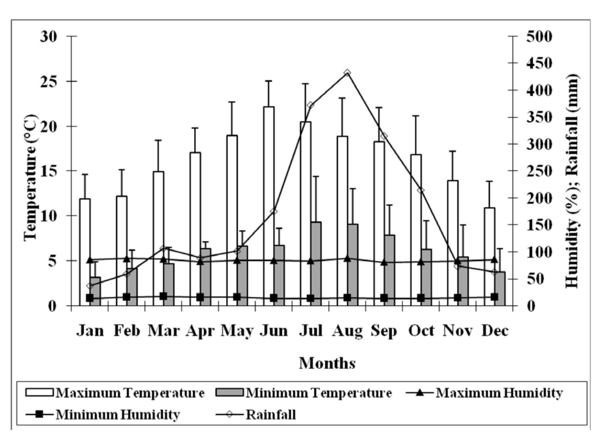

Fig. 2. Meteorological data of the study area (1998-2007) (Source: Uttarakhand Forest Department)

lies in the central axis of the great Himalaya, which consists of belts of metamorphic rocks; includes gneisses, granites and schists, known as the central crystalline groups. Most of the rocks in the study area are fine to coarse-grained schists, all very much interleaved. Meteorological details (1998-2007) of the study are given in Fig. 2. Mean annual maximum and minimum temperature were recorded as 16.41±3.60 °C and 6.14±1.98 °C respectively. Mean annual rainfall was recorded as 2044.47±476.01 mm. Mean relative humidity round the year ranged from 15% to 86%.

Sampling and data analysis

After the reconnaissance survey five forest categories according to altitude, slope aspect and dominant tree species were selected for the study (Table 1). Physiographic factors i.e., altitude, and aspect across different cover types were measured by GPS (Garmin, Rino-130). The composition of the forest types was analyzed by using nested quadrat method as per Kent and Coker (1992). Trees (≥10 cm dbh), shrubs and herbs were analyzed by 10m × 10m, 5m × 5m and 1m × 1m sized quadrats, respectively as proposed by Curtis and McIntosh (1950) and Phillips (1959). Density (Nha^{-1}) and basal cover (G) were calculated for each species. Frequency, density and abundance were calculated following Curtis and McIntosh (1950). Species richness (SR) was simply taken as a count of total number of species in that particular forest type. The Importance Value Index (Phillips, 1959), Shannon-Wiener diversity index (Shannon and Weaver, 1963), Simpson concentration of dominance (Simpson, 1949), Pielou equitability (Pielou, 1966), Margalef index of species richness (Margalef, 1958), Menheink index of species richness (Whittaker, 1977), species heterogeneity and beta diversity (Whittaker, 1972) were calculated with the following formulae:

$$IVI = (R_F + R_D + R_{Do}) \quad (1)$$

$$\overline{H} = -\sum_{i=1}^{s}\left(\frac{n_i}{n}\right)\log_2\left(\frac{n_i}{n}\right) \quad (2)$$

$$Cd = \sum_{i=1}^{s} P_i^2 \quad (3)$$

$$\sum_{i=1}^{s} P_i^2 = \sum \frac{n_i}{n} \quad (4)$$

$$E_P = \frac{\overline{H}}{\overline{H}_{max}} \quad (5)$$

$$\overline{H}_{max} = \ln_s \quad (6)$$

$$MI = \frac{S-1}{\ln(N)} \quad (7)$$

$$MeI = \frac{S}{\sqrt{N}} \quad (8)$$

$$H_g = \sqrt{Cd} \quad (9)$$

$$\beta_{Div} = \frac{S_c}{S_a} \quad (10)$$

where, Cd is Simpson concentration of dominance, E_P is Pielou equitability, H_g is species heterogeneity, $\overline{H}$ is Shannon-Wiener diversity index, IVI is Importance Value Index, lnS is natural log of S, MeI is Menheink index of species richness, MI is Margalef index of species richness,

Table 1. General details of the studied forest types.

FT	Forest Type	Altitude (m asl)	Slope aspect (facing)
FT1	Mixed Abies pindrow	2500-2100	South
FT2	Mixed broad-leaved	2400-2150	North-east
FT3	Mixed broad-leaved	2150-1900	North-east
FT4	Mixed broad-leaved	1900-1600	North
FT5	Mixed *Quercus leucotrichophora*	1650-1500	North-east

n is total IVI values of all species, N is total number of individuals, n_i is the IVI value of a species, R_D is relative density, R_{Do} is relative dominance, R_F is relative frequency, S is total number of species in forest type, S_a is average number of species per stand, S_c is total number of species in all stands, and β_{Div} is Beta Diversity.

To ascertain the resource apportionment among various species in different forest types, dominance-diversity (d-d) curves were drawn. The relative importance value is an expressive measure of niche of species, thus treated as an expression of the relative niche size. The dominance-diversity curves were drawn by a co-ordinate point of its relative importance index (IVI) on the y-axis and its position in the sequence of species from highest to lowest IVI on the x-axis (Whittaker, 1975) for tree, shrub and herb layers.

RESULTS AND DISCUSSION

The middle altitudinal zone of western Himalaya is characterized by extensive oak and coniferous forests. The values of Nha^{-1}, G, Shannon-Wiener diversity index ($\overline{H}$) and Simpson concentration of dominance (Cd) for different species in tree, shrub and herb strata are placed in Tables 2, 3 and 4, respectively. These community characters varied markedly among different aspects and altitudes. Total values of phytosociological and diversity indices in different forest types are placed in Table 5. Comparison between phytosociological and diversity indices of tree strata at various altitudes in different parts of the Uttarakhand Himalaya (earlier reported values) and the study area is given in Table 6.

Abies pindrow was dominant tree species between 2100 and 2500 masl on southern aspect (IVI=89.91; G= 39.8 m^2ha^{-1}; stem density= 390 Nha^{-1}; $\overline{H}$= 0.52; Cd= 0.0898). It showed very feeble presence between 2150 and 2400 masl on north-east aspect (IVI= 7.75; G= 4.29 m^2ha^{-1}; stem density= 7 Nha^{-1}; $\overline{H}$= 0.14; Cd= 0.0007). Lower altitudes and moderate slopes constitute suitable habitat conditions for many tree species, but *A. pindrow* preferred higher altitudes and steeper slopes. Therefore, *A. pindrow* was not present in the forest types below 2100 masl. The average Nha^{-1} and G values of *A. pindrow* in the present study were comparable to the earlier recorded values for the *A. pindrow* forests of the temperate Himalaya (Baduni, 1996; Dhar et al., 1997; Sharma and Baduni, 2000; Sharma et al., 2001). The stem density of *A. pindrow* varied from 7 to 390 Nha^{-1}, which were relatively low, when compared with values reported by Sharma and Baduni (2000) for pure *A. pindrow* forests (440 to 550 Nha^{-1}) in Garhwal Himalaya. The G of *A. pindrow* in the present study ranged from 4.29 to 39.8 m^2ha^{-1}, which was slightly higher than the values (35.66 m^2ha^{-1}) reported by Sharma et al. (2001). It was because comparatively old growth forests of *A. pindrow* were present in the study area.

Quercus floribunda was found distributed between 2100 and 2500 masl. It was co-dominant of *A. pindrow* from 2100 to 2500 masl on southern aspect. With other broadleaved tree species *Q. floribunda* (IVI= 62.98; G= 13.48 m^2ha^{-1}; stem density= 93 Nha^{-1}; $\overline{H}$= 0.47; Cd= 0.0441) formed good portion of mixed broad-leaf forest type (FT2) between 2150 and 2400 masl on north-east aspect. *Q. leucotrichophora* was distributed between 1500 and 2400 masl. It was dominant at lower altitudes of the study area between 1500 and 1650 masl on north-east aspect (IVI= 123.61; G= 16.52 m^2ha^{-1}; stem density= 490 Nha^{-1}; $\overline{H}$= 0.53; Cd= 0.170). However, at other altitudes and aspects it was found growing as a co-dominant or associated tree species. *Q. leucotrichophora* has contributed feebly to total forest composition between 2150 and 2400 masl on north-east aspect (IVI= 19.53; G= 5.75 m^2ha^{-1}; stem density= 67 Nha^{-1}; $\overline{H}$= 0.26; Cd= 0.004). In association with other broadleaved tree species, *Q. leucotrichophora* formed moderate portions of forests between 1900 and 2150 masl on north-east aspect (IVI= 56.47; G= 10.01 m^2ha^{-1}; stem density= 120 Nha^{-1}; $\overline{H}$= 0.45; Cd= 0.035) and between 1600 and 1900 masl on north aspect (IVI= 48.02; G= 20.99 m^2ha^{-1}; stem density= 160 Nha^{-1}; $\overline{H}$= 0.42; Cd= 0.026). In western Himalaya, the Pinus roxburghii is considered to be an early successional species whereas *Quercus* spp. and *A. pindrow* are considered to be climax species (Champion and Seth, 1968).

Lyonia ovalifolia and *Rhododendron arboreum* were

Table 2. Community composition and diversity in tree strata

Species	FT1		FT2		FT3		FT4		FT5	
	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha-1 (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha-1 (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)
Abies pindrow	390 (39.80)	0.52 (0.0898)	7 (4.29)	0.14 (0.0007)	-	-	-	-	-	-
A. spectabilis	-	-	7 (0.05)	0.05 (0.0001)	-	-	-	-	-	-
Aesculus indica	110 (11.70)	0.34 (0.0114)	27 (10.84)	0.27 (0.0050)	-	-	-	-	-	-
Alnus nepalensis	-	-	-	-	33 (2.54)	0.23 (0.0030)	110 (11.01)	0.34 (0.0104)	10 (1.84)	0.15 (0.0009)
Betula alnoides	100 (5.64)	0.29 (0.0064)	100 (4.83)	0.28 (0.0057)	93 (5.45)	0.34 (0.0113)	210 (17.22)	0.42 (0.0257)	-	-
Buxus wallichiana	-	-	7 (0.24)	0.06 (0.0001)	-	-	-	-	-	-
Carpinus viminea	90 (1.26)	0.20 (0.0021)	73 (2.42)	0.21 (0.0022)	107 (2.08)	0.32 (0.0084)	35 (2.43)	0.16 (0.0010)	-	-
Cupressus torulosa	-	-	-	-	-	-	10 (0.26)	0.05 (0.0000)	-	-
Daphniphyllum himalense	100 (2.60)	0.24 (0.0034)	13 (0.31)	0.07 (0.0001)	220 (5.27)	0.44 (0.0321)	430 (17.46)	0.48 (0.0493)	-	-
Diospyros montana	-	-	13 (0.24)	0.09 (0.0002)	13 (0.06)	0.09 (0.0002)	10 (0.08)	0.07 (0.0001)	-	-
Dodecademia grandiflora	50 (0.81)	0.15 (0.0009)	-	-	-	-	-	-	-	-
Euonymus tingens	30 (0.47)	0.13 (0.0006)	-	-	-	-	-	-	-	-
Ficus roxburghii	-	-	-	-	-	-	-	-	10 (0.76)	0.11 (0.0004)
F. subincisa	-	-	-	-	-	-	-	-	10 (0.34)	0.09 (0.0002)
Fraxinus micrantha	-	-	7 (0.06)	0.05 (0.0001)	-	-	10 (0.11)	0.07 (0.0001)	-	-
Juglans regia	-	-	7 (0.30)	0.06 (0.0001)	-	-	-	-	-	-
Lyonia ovalifolia	40 (0.61)	0.14 (0.0007)	107 (6.24)	0.34 (0.0111)	47 (1.58)	0.20 (0.0021)	120 (2.22)	0.26 (0.0043)	130 (1.36)	0.35 (0.0123)
Myrica esculenta	-	-	-	-	-	-	-	-	160 (11.63)	0.49 (0.0559)
Neolitsea pallens	110 (4.64)	0.28 (0.0054)	53 (2.41)	0.17 (0.0013)	13 (0.14)	0.10 (0.0003)	-	-	-	-
Persea duthiei	200 (4.34)	0.35 (0.0118)	447 (9.58)	0.48 (0.0509)	267 (6.22)	0.45 (0.0349)	-	-	-	-
P. odoratissima	-	-	-	-	-	-	185 (8.60)	0.37 (0.0154)	-	-
Pyrus pashia	-	-	-	-	13 (0.08)	0.10 (0.0003)	10 (0.11)	0.07 (0.0001)	120 (1.49)	0.35 (0.0118)
Quercus floribunda	90 (11.01)	0.32 (0.0089)	140 (22.92)	0.46 (0.0370)	-	-	-	-	-	-
Q. leucotrichophora	-	-	67 (5.75)	0.26 (0.0042)	120 (10.01)	0.45 (0.0354)	160 (20.99)	0.42 (0.0256)	490 (16.52)	0.53 (0.1698)
Rhododendron arboreum	80 (1.17)	0.22 (0.0028)	127 (6.33)	0.33 (0.0101)	67 (3.81)	0.30 (0.0069)	165 (3.55)	0.29 (0.0066)	40 (0.31)	0.17 (0.0012)
Symplocos paniculata	-	-	-	-	7 (0.06)	0.06 (0.0001)	-	-	-	-
Toona ciliata	-	-	-	-	-	-	-	-	10 (0.64)	0.11 (0.0003)
Ulmus wallichiana	-	-	-	-	7 (0.05)	0.06 (0.0001)	15 (0.21)	0.09 (0.0002)	10 (0.19)	0.09 (0.0002)
	1390 (84.03)	3.19 (0.1442)	1200 (76.83)	3.33 (0.1289)	1007 (37.37)	3.14 (0.1350)	1470 (84.25)	3.09 (0.1389)	990 (35.08)	2.43 (0.2530)

Abbreviations: Nha^{-1} = stem density; G= total basal cover (m^2ha^{-1}) $\overline{H}$ = Shannon-Wiener diversity index; Cd= Simpson concentration of dominance.

Table 3. Community composition and diversity in shrub strata

Species	FT1		FT2		FT3		FT4		FT5	
	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)
Berberis aristata	453 (0.261)	0.30 (0.0068)	-	-	436 (0.382)	0.29 (0.0062)	-	-	-	-
B. asiatica	-	-	-	-	-	-	1173 (1.029)	0.42 (0.0241)	2907 (2.551)	0.43 (0.0273)
Boehmeria platyphylla	-	-	-	-	-	-	-	-	1253 (0.302)	0.25 (0.0039)
Boenninghausenia albiflora	-	-	-	-	27 (0.004)	0.05 (0.0000)	-	-	-	-
Clematis barbellata	-	-	-	-	-	-	80 (0.071)	0.08 (0.0002)	-	-
Cotoneaster microphyllus	-	-	-	-	-	-	-	-	640 (0.215)	0.19 (0.0017)
Daphne papyracea	-	-	-	-	222 (0.019)	0.14 (0.0007)	338 (0.039)	0.16 (0.0010)	-	-
Desmodium elegans	-	-	-	-	-	-	53 (0.041)	0.08 (0.0001)	560 (0.589)	0.23 (0.0030)
Elaeagnus parvifolia	-	-	-	-	-	-	284 (0.428)	0.26 (0.0044)	-	
Elsholtzia flava	1173 (0.284)	0.38 (0.0168)	-	-	62 (0.021)	0.05 (0.0001)	-	-	-	
E. fruticosa	-	-	-	-	151 (0.076)	0.12 (0.0004)	-	-	-	
Eupatorium adenophorum	-	-	-	-	773 (0.186)	0.23 (0.0032)	2533 (0.610)	0.40 (0.0194)	11893 (2.570)	0.52 (0.0840)
Hedera nepalensis	-	-	80 (0.070)	0.20 (0.0019)	453 (0.455)	0.30 (0.0071)	-	-	1173 (1.459)	0.32 (0.0088)
Hypericum uralum	-	-	80 (0.016)	0.15 (0.0008)	36 (0.007)	0.04 (0.0000)	-	-	-	
Indigofera heterantha	-	-	-	-	-	-	160 (0.140)	0.16 (0.0010)	347 (0.365)	0.18 (0.0014)
Jasminum officinale	-	-	-	-	151 (0.068)	0.18 (0.0014)	-	-	-	-
Leptodermis lanceolata	-	-	-	-	-	-	-	-	507 (0.227)	0.20 (0.0019)
Plectranthus striatus	-	-	-	-	-	-	36 (0.006)	0.05 (0.0000)	-	-
Randia tetrasperma	-	-	-	-	18 (0.018)	0.04 (0.0000)	36 (0.026)	0.06 (0.0001)	-	-
Rosa brunonii	-	-	-	-	240 (0.654)	0.29 (0.0061)	-	-	-	-
Rubus ellipticus	1413 (0.817)	0.49 (0.0579)	453 (0.0309)	0.42 (0.0244)	720 (0.490)	0.34 (0.0112)	453 (0.203)	0.22 (0.0026)	-	-
R. foliolosus	-	-	-	-	249 (0.182)	0.19 (0.0017)	116 (0.062)	-	-	-
R. foliolosus	-	-	-	-	-	-	-	0.09 (0.0002)	-	-
R. nepalensis	-	-	-	-	160 (0.102)	0.13 (0.0006)	1351 (0.646)	0.40 (0.0208)	-	-
Sarcococca saligna	-	-	-	-	1191 (0.223)	0.33 (0.0094)	98 (0.014)	0.07 (0.0001)	-	-
Senecio kunthianus	613 (0.097)	0.27 (0.0052)	1493 (0.186)	0.50 (0.0653)	-	-	-	-	-	-
Sinarundinaria falcata	-	-	-	-	-	-	4080 (0.906)	0.49 (0.0579)	4933 (0.795)	0.38 (0.0162)
Smilax menispermoidea	-	-	-	-	-	-	71 (0.015)	0.07 (0.0001)	-	-
Solanum erianthum	-	-	-	-	-	-	89 (0.014)	0.08 (0.0002)	-	-
Sorbaria tomentosa	267 (0.192)	0.24 (0.0036)	-	-	-	-	-	-	-	-
Strobilanthes atropurpureus	-	-	-	-	347 (0.041)	0.20 (0.0019)	222 (0.032)	0.14 (0.0008)	-	-
Thamnocalamus falconeri	800 (0.114)	0.27 (0.0047)	1013 (0.143)	0.37 (0.0142)	3582 (0.515)	0.48 (0.0486)	-	-	-	-
T. spathiflora	4720 (0.734)	0.53 (0.1200)	3573 (0.516)	0.53 (0.1581)	676 (0.124)	0.24 (0.0035)	-	-	-	-
Urtica dioica	-	-	-	-	-	-	124 (0.109)	0.12 (0.0004)	-	-
Zanthoxylum armatum	-	-	-	-	-	-	-	-	640 (1.759)	0.30 (0.0072)
	9440 (2.498)	2.49 (0.2150)	6693 (1.239)	2.16 (0.2647)	9493 (3.568)	3.64 (0.1023)	11298 (4.394)	3.35 (0.1335)	24853 (10.835)	2.99 (0.1553)

Abbreviations: Nha^{-1} = density; G= total basal cover (m^{2}ha^{-1}) $\overline{H}$ = Shannon-Wiener diversity index; Cd= Simpson concentration of dominance.

Table 4. Community composition and diversity in herb strata

Species	FT1		FT2		FT3		FT4		FT5	
	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)	Nha^{-1} (G)	$\overline{H}$ (Cd)
Adenocaulon himalaicum	-	-	6400 (0.624)	0.13 (0.0006)	-	-	-	-	-	-
Agrimonia pilosa	-	-	3200 (0.193)	0.08 (0.0002)	6500 (0.423)	0.16 (0.0010)	500 (0.025)	0.04 (0.0000)	-	-
Ainsliaea aptera	11000 (0.268)	0.20 (0.0019)	800 (0.019)	0.03 (0.0000)	-	-	-	-	-	-
A. latifolia	-	-	9200 (0.339)	0.13 (0.0006)	500 (0.018)	0.04 (0.0000)	5000 (0.151)	0.11 (0.0004)	-	-
Ajuga parviflora	-	-	-	-	-	-	1000 (0.024)	0.04 (0.0000)	11000 (0.386)	0.15 (0.0008)
Anaphalis contorta	-	-	-	-	-	-	-	-	11000 (0.526)	0.14 (0.0007)
A. triplinervis	-	-	4800 (0.193)	0.08 (0.0002)	-	-	-	-	-	-
Arabis amplexicaulis	-	-	-	-	-	-	3000 (0.054)	0.08 (0.0002)	-	-
Arenaria orbiculata	-	-	10000 (0.058)	0.07 (0.0001)	-	-	-	-	-	-
Calanthe plantaginea	-	-	-	-	500 (0.056)	0.04 (0.0000)	-	-	-	-
Centella asiatica	-	-	4800 (0.034)	0.06 (0.0001)	8000 (0.053)	0.15 (0.0009)	13500 (0.087)	0.17 (0.0013)	18000 (0.081)	0.13 (0.0006)
Cerastium glomeratum	-	-	4800 (0.019)	0.05 (0.0000)	-	-	-	-	-	-
Cirsium verutum	-	-	800 (0.157)	0.05 (0.0000)	-	-	-	-	-	-
Clinopodium umbrosum	-	-	-	-	13000 (0.045)	0.22 (0.0025)	3000 (0.005)	0.05 (0.0000)	14000 (0.101)	0.12 (0.0004)
Cynoglossum zeyalanicum	-	-	-	-	-	-	-	-	10000 (0.790)	0.15 (0.0009)
Delphinium denudatum	-	-	6000 (0.520)	0.12 (0.0005)	1000 (0.060)	0.05 (0.0000)	-	-	-	-
Elsholtzia pilosa	-	-	400 (0.007)	0.02 (0.0000)	-	-	-	-	-	-
Fragaria nubicola	36000 (1.325)	0.38 (0.0173)	37600 (0.119)	0.27 (0.0051)	29500 (0.939)	0.33 (0.0096)	50500 (1.303)	0.42 (0.0252)	48000 (0.597)	0.24 (0.0035)
Galinsoga parviflora	13000 (0.162)	0.18 (0.0014)	-	-	-	-	-	-	45000 (0.434)	0.20 (0.0021)
Galium aparine	-	-	-	-	-	-	-	-	8500 (0.038)	0.09 (0.0002)
G. asperifolium	46000 (0.352)	0.34 (0.0110)	34400 (0.198)	0.21 (0.0024)	16000 (0.054)	0.19 (0.0018)	33500 (0.193)	0.28 (0.0056)	-	-
Gentiana capitata	24000 (0.148)	0.23 (0.0032)	7200 (0.024)	0.08 (0.0002)	-	-	-	-	-	-
G. pedicellata	-	-	2400 (0.014)	0.03 (0.0000)	-	-	1500 (0.008)	0.06 (0.0001)	-	-
Geranium ocellatum	-	-	-	-	-	-	7000 (0.080)	0.12 (0.0005)	12000 (0.149)	0.12 (0.0004)
Gnaphalium affine	-	-	-	-	-	-	-	-	12000 (0.484)	0.15 (0.0008)
Gonatanthus pumilus	-	-	-	-	2000 (0.195)	0.08 (0.0002)	-	-	-	-
Hedychium spicatum	-	-	-	-	1000 (0.112)	0.06 (0.0001)	-	-	-	-
Hemiphragma heterophyllum	-	-	17600 (0.106)	0.12 (0.0005)	7000 (0.040)	0.09 (0.0002)	-	-	-	-
Impatiens scabrida	-	-	-	-	2000 (0.168)	0.08 (0.0002)	-	-	-	-
I. sulcata	-	-	-	-	4500 (0.504)	0.19 (0.0017)	-	-	-	-
Lamium album	-	-	92400 (3.724)	0.45 (0.0344)	30500 (2.890)	0.46 (0.0388)	20500 (1.234)	0.35 (0.0122)	-	-
Lysimachia pyramidalis	-	-	32000 (0.206)	0.16 (0.0010)	-	-	-	-	-	-
Mazus surculosus	-	-	-	-	-	-	-	-	18000 (0.632)	0.17 (0.0013)
Mentha arvensis	-	-	-	-	-	-	-	-	12000 (0.723)	0.15 (0.0009)

Table 4. Continued

Micromeria biflora	-	-	-	-	-	-	-	-	18000 (0.070)	0.13 (0.0006)
Origanum vulgare	35000 (0.234)	0.41 (0.0232)	11600 (0.624)	0.14 (0.0007)	-	-	2000 (0.125)	0.07 (0.0001)	36000 (2.328)	0.29 (0.0065)
Oxalis corniculata	-	-	4800 (0.059)	0.06 (0.0001)	5000 (0.062)	0.10 (0.0003)	5000 (0.057)	0.09 (0.0002)	60500 (0.583)	0.25 (0.0042)
Paris polyphylla	-	-	14800 (1.657)	0.26 (0.0042)	5500 (0.521)	0.22 (0.0025)	2500 (0.244)	0.12 (0.0004)	-	-
Parochetus communis	37000 (0.356)	0.28 (0.0055)	32800 (0.147)	0.20 (0.0019)	9000 (0.087)	0.13 (0.0005)	6000 (0.027)	0.09 (0.0002)	-	-
Pedicularis bifida	-	-	7200 (0.176)	0.07 (0.0001)	-	-	-	-	-	-
Peperomia tetraphylla	-	-	-	-	20000 (0.048)	0.19 (0.0017)	8000 (0.023)	0.13 (0.0006)	-	-
Peristrophe paniculata	-	-	-	-	-	-	-	-	7500 (0.461)	0.12 (0.0005)
P. speciosa	-	-	-	-	-	-	-	-	9500 (0.531)	0.14 (0.0007)
Persicaria capitata	-	-	-	-	-	-	-	-	17000 (1.301)	0.20 (0.0021)
P. hydropiper	31000 (0.632)	0.32 (0.0091)	8800 (0.355)	0.14 (0.0007)	-	-	3000 (0.073)	0.07 (0.0001)	14000 (0.492)	0.14 (0.0007)
Pilea umbrosa	-	-	4800 (0.468)	0.10 (0.0003)	-	-	-	-	-	-
Plantago depressa	-	-	3600 (0.351)	0.09 (0.0002)	-	-	1000 (0.060)	0.05 (0.0001)	11000 (1.042)	0.18 (0.0014)
Potentilla fulgens	-	-	2800 (0.273)	0.09 (0.0002)	-	-	-	-	-	-
Pouzolzia zeylanica	-	-	-	-	-	-	-	-	9500 (0.400)	0.13 (0.0006)
Prunella vulgaris	41000 (0.686)	0.32 (0.0091)	13600 (0.677)	0.16 (0.0011)	-	-	-	-	-	-
Rubia manjith	-	-	6800 (0.274)	0.11 (0.0004)	2500 (0.101)	0.09 (0.0002)	500 (0.018)	0.04 (0.0000)	-	-
Rumex hastatus	-	-	-	-	-	-	1000 (0.060)	0.05 (0.0001)	11500 (0.909)	0.17 (0.0012)
R. nepalensis	-	-	2400 (0.269)	0.07 (0.0001)	-	-	-	-	-	-
Salvia nubicola	7000 (0.683)	0.24 (0.0035)	-	-	500 (0.047)	0.04 (0.0000)	-	-	-	-
Scutellaria scandens	-	-	-	-	16500 (1.388)	0.33 (0.0103)	17500 (1.339)	0.35 (0.0117)	9500 (0.658)	0.15 (0.0008)
Senecio nudicaulis	-	-	1600 (0.135)	0.05 (0.0000)	1000 (0.089)	0.07 (0.0001)	-	-	-	-
Solanum nigrum	-	-	-	-	-	-	-	-	6000 (0.058)	0.08 (0.0002)
Sonchus brachyotus	-	-	-	-	-	-	-	-	6000 (0.416)	0.13 (0.0006)
Stellaria media	-	-	24000 (0.585)	0.21 (0.0022)	12000 (0.215)	0.20 (0.0020)	57000 (0.994)	0.40 (0.0212)	30000 (0.373)	0.17 (0.0013)
Swertia chirayita	-	-	800 (0.032)	0.03 (0.0000)	-	-	-	-	-	-
Taraxacum officinale	-	-	-	-	4000 (0.154)	0.10 (0.0003)	2000 (0.081)	0.06 (0.0001)	26000 (2.187)	0.27 (0.0052)
Thalictrum foliolosum	-	-	-	-	2000 (0.153)	0.09 (0.0002)	10500 (0.632)	0.25 (0.0037)	-	
Trifolium repens	-	-	10400 (0.109)	0.12 (0.0005)	7000 (0.282)	0.19 (0.0016)	8000 (0.195)	0.17 (0.0012)	48500 (0.704)	0.24 (0.0033)
Viola betonicifolia	13000 (0.456)	0.25 (0.0037)	-	-	-	-	-	-	-	-
V. canescens	-	-	25200 (0.687)	0.25 (0.0038)	-	-	-	-	-	-
V. pilosa	-	-	-	-	17000 (0.368)	0.25 (0.0038)	19500 (0.205)	0.26 (0.0043)	10500 (0.176)	0.11 (0.0004)
	315000 (8.723)	3.47 (0.0968)	464800 (16.079)	4.53 (0.0653)	224000 (90748.4)	4.14 (0.0806)	282500 (7.297)	3.92 (0.0895)	550500 (17.627)	4.70 (0.0426)

Abbreviations: Nha^{-1} = stem density; G= total basal cover (m^2ha^{-1}) $\overline{H}$ = Shannon-Wiener diversity index; Cd= Simpson concentration of dominance.

distributed throughout the study area but showed varied values for phytosociological and diversity indices at different altitudes. Both species acted as associates of different tree species at various altitudes. Stem density, G, $\overline{H}$ and Cd values of *L. ovalifolia* in the study area ranged from 40 to 130 Nha^{-1}, 0.61 to 6.24 m^2ha^{-1}, 0.14 to 0.35 and 0.0007 to 0.0123, respectively. Whereas stem density, G, $\overline{H}$ and Cd values of *R. arboreum* in the study area ranged from 40 to 165 Nha^{-1}, 0.31 to 6.33 m^2ha^{-1}, 0.17 to 0.33 and 0.0012 to 0.0101, respectively. The results showed that both *L. ovalifolia* and *R. arboreum* were well adapted to various altitudes and aspects, which helped them to flourish throughout the study area. *Persea duthiei, Neolitsea pallens*, *Betula alnoides*, *Carpinus viminea*, *Daphniphyllum himalense*, *Pyrus pashia*, and *Persea odoratissima* formed co-dominant flora at various altitudes in different proportions. Occurrence of these species almost in each forest type suggested their wider ecological amplitude.

There is wide variation in the range of Gof the tree species and values of G in the present study are best fitted with the earlier reported values for Uttarakhand Himalaya (Table 6). The highest G (84.25 m^2ha^{-1}) was recorded between 1600 and 1900 masl, whereas lowest G (35.08 m^2ha^{-1}) was recorded between 1500 and 1650 masl. However value of G for oak dominated forests of the study area were higher than the values recorded by Saxena and Singh (1982), Singh et al. (1994) and Kumar and Ram (2005) from Kumaun Himalaya and Ghildiyal et al. (1998), Baduni and Sharma (1999) and Sharma et al. (2001) from Garhwal Himalaya (Table 6). Generally in *Quercus* spp. dominated forests of Uttarakhand Himalaya lots of anthropogenic disturbances like lopping, stem cutting, grazing, fuel wood collection, etc are prevalent. But in our study area these forests were protected and mature, which seems to have reached their higher limit of productivity. These could be the possible reasons for high G values in this forest. According to Saxena et al. (1978) the trees with higher G indicate the best performance of the species in a particular set of environmental conditions and lower G either demarcate the chance occurrence of the species or presence of the biotic disturbances in the past.

In the present investigation total stem density ranged

Table 5. Total values of phytosociological and diversity indices

FT	VL	Nha^{-1}	G	$\overline{H}$	Cd	Eq	SR	MI	MeI	βDiv
FT1	Tree	1390	84.03	3.19	0.1442	0.89	12	1.55	1.02	1.74
	Shrub	9440	2.50	2.49	0.2150	0.89	7	0.71	0.37	1.98
	Herb	315000	8.72	3.47	0.0968	0.97	12	1.18	0.48	3.08
FT2	Tree	1200	76.83	3.33	0.1289	0.83	16	2.17	1.46	3.63
	Shrub	6693	1.24	2.16	0.2647	0.83	6	0.63	0.38	2.73
	Herb	464800	16.08	4.53	0.0653	0.88	36	3.44	1.06	6.67
FT3	Tree	1007	37.37	3.14	0.1350	0.85	13	1.80	1.30	3.15
	Shrub	9493	3.57	3.64	0.1023	0.87	18	1.69	0.55	4.20
	Herb	224000	9.07	4.14	0.0806	0.87	27	2.95	1.28	5.24
FT4	Tree	1470	84.25	3.09	0.1389	0.84	13	1.67	1.07	2.89
	Shrub	11298	4.39	3.35	0.1335	0.80	18	1.65	0.50	4.48
	Herb	282500	7.30	3.92	0.0895	0.83	26	2.73	1.09	5.15
FT5	Tree	990	35.08	2.43	0.2530	0.73	10	1.36	1.01	2.70
	Shrub	24853	10.83	2.99	0.1553	0.90	10	0.91	0.33	1.65
	Herb	550500	17.63	4.70	0.0426	0.97	29	2.77	0.87	3.65

Abbreviations: VL= Vegetation layer; Nha^{-1}= stem density; G= total basal cover (m^2ha^{-1}) $\overline{H}$= Shannon-Wiener diversity index; Cd= Simpson concentration of dominance; Eq= Pielou equitability; SR= Species richness; MI= Margalef index of species richness; MeI= Menheink index of species richness; β_{Div}= Beta diversity.

from 990 to 1470 Nha^{-1}. Saxena and Singh (1982) observed a range of stem density from 420 to 1300 Nha^{-1} for a temperate forest in Kumaun Himalaya. In temperate forests of Garhwal Himalaya Pant (1987) reported total density ranging from 720 to 2060 Nha^{-1}, whereas Nayak et al. (1991) reported it between 500 and 1620 Nha^{-1}. High values of Nha^{-1} in FT1 and FT4 were due to presence of various undercanopy and sub-canopy tree species like *C. viminea*, *D. himalense*, *D. grandiflora*, *E. tingens*, *L. ovalifolia*, *N. pallens*, *P. duthiei* and *R. arboreum*, which had high Nha^{-1} but low G. Values of Nha^{-1} in the study area were higher than earlier recorded values in most of the forests of Uttarakhand Himalaya (Table 6). It can be attributed to the fact that this forest had higher species diversity and was almost free from anthropogenic disturbances. These reasons enabled many tree species to utilize the niche efficiently in the area to form stable, mature and productive communities.

The values of species diversity were comparable to those reported for other temperate forests (Table 6). Shannon-Wiener diversity index ($\overline{H}$) ranged between 3.33 and 2.43. The mean $\overline{H}$ values reported for the different forests of Uttarakhand Himalaya varied from 0.4 to 2.8 (Singh et al., 1994) and 1.55 to 1.97 (Mishra et al., 2000). $\overline{H}$ in mixed broad-leaved forests (FT2 to FT4) varied between 3.09 and 3.33, which were higher than the values recorded by Khera et al. (2001) for Kumaun Himalaya (1.6 to 2.8) and Kumar and Ram (2005) for Hanumangarh area of Kumaun Himalaya (2.7). $\overline{H}$ in *Q. leucotrichophora* dominated forest type was recorded as 2.43, which was exactly same as was recorded by Pandey (2003) for Shitlakhet area of Kumaun Himalaya. However, it was higher than the $\overline{H}$ value recorded by Sanjeev et al. (2006) for Mussorie Dehradun (1.68) and lower than the value recorded by Kumar and Ram (2005) for Gagar area of Kumaun Himalaya (2.50). Comparison between $\overline{H}$ values of the present study with those of similar forests in other parts of Uttarakhand Himalaya (Table 6) shows that Mandal-Chopta forest is more diverse than most of the other forests. This may be because of its protected status and wide range in topography. Putman (1994) also stated that diversity tends to increase as the environment becomes more favourable and more predictable.

The total values of Cd ranged from 0.129 to 0.253 in tree layer, 0.102 to 0.265 in shrub layer and 0.043 to 0.097 in herb layer. These values were more or less similar to the earlier reported values for temperate forests. Mean Cd values of 0.31 to 0.42 (Mishra et al., 2000) and 0.11 to 0.93 (Tiwari and Singh, 1985) were reported from different parts of Uttarakhand Himalaya. The low values of Cd were due to high species richness. The value of Cd in *A. pindrow* dominated forest (FT1) was recorded as 0.14, which is lower than the recorded values (0.29-0.57) by Sharma et al. (2010a) in *A. pindrow* dominated forests of Chaurangikhal area of Garhwal Himalaya. Values of Cd for mixed broad leaved forests (FT2 to FT5) of the study area were lower than the values recorded by Khera et al. (2001) for similar forests of Kumaun Himalaya (0.15 to 0.43). Cd of *Q. leucotrichophora* dominated forest type (FT5) of the study area was lower (0.25) than the value of Cd (0.34) recorded by Sanjeev et al. (2006) for similar forest in Mussorie hills, Dehradun. According to Baduni and Sharma (1997) the Cd is strongly affected by the IVI of the first three relatively important species in a community. $\overline{H}$ and Cd were inversely related with each other in the study area, which is generally the case in established forests (Zobel et al., 1976).

The values of Pielou equitability ranged from 0.73 to 0.89 in tree layer, 0.83 to 0.90 in shrub layer and 0.83 to 0.97 in herb layer. Kumar and Ram (2005) and Srivastava et al. (2005) recorded similar values for tree and shrub layers of forests of Kumaun and Garhwal Himalaya respectively, whereas values of equitability recorded for tree layer by Sharma et al. (1999) for Trikuta Hills of Jammu and Ghildiyal et al. (1998) for Chamoli Garhwal were higher than the presently recorded values. Inter community or inter-habitat diversity is termed as β-Diversity. It is also defined as extent of species replacement or species turnover along an environmental gradient (Whittaker, 1972). The values of β-Diversity varied from 1.74 to 3.63 for tree layer, 1.65 to 4.48 for shrub layer and 2.06 to 6.67 for herb layer. Earlier Negi and Nautiyal (2005) reported the β -Diversity values as 1.42 for tree strata and 1.30 for shrub strata of Thal Ke Dhar Forest (Pithoragarh, Kumaun),

Table 6. Comparison between phytosociological and diversity indices in various forest types of the Uttarakhand Himalaya (earlier reported values) and the study area

Forest Type	(Source)Locality	Altitude (m asl)	Nha-1	G	$\overline{H}$	Cd
Abies pindrow mixed broadleaf	(1) Mandal-Chopta, Chamoli Garhwal	2100-2500	1390	84.03	3.19	0.14
Conifer mixed broadleaf	(2) Chakrata, Dehradun Garhwal	2000-2100	451-664	70.90-93.90	-	-
A. pindrow	(3) Kumaun	2260-2750	420-680	54.00-124.00	-	-
Conifer mixed broadleaf	(4) VOFNP, Chamoli Garhwal	-	338	49.76	-	-
Cupressus- Quercus spp.	(5) Kumaun	1300-2600	300	-	-	-
Mixed broadleaf	(1) Mandal-Chopta, Chamoli Garhwal	1600-1900	1470	84.25	3.09	0.138
Mixed broadleaf	(1) Mandal-Chopta, Chamoli Garhwal	1900-2150	1007	37.37	3.14	0.135
Mixed broadleaf	(1) Mandal-Chopta, Chamoli Garhwal	2150-2400	1200	76.83	3.33	0.128
Mixed broadleaf	(6) Nainital, Kumaun	1300-2000	320-660	4.50-16.80	1.60-2.80	0.15-0.43
Mixed broadleaf	(7) Hanumangarh, Kumaun	1600-1800	600	15.00	2.70	-
Q. floribunda	(5) Kumaun	1300-2600	240	-	-	-
Q. floribunda	(8) Dudhatoli, Pauri Garhwal	-	250-340	18.45-38.25	-	-
Q. floribunda	(9) Mandal, Chamoli Garhwal	-	366-466	24.00-29.00	-	-
Q. floribunda	(7) Mukteshwer, Kumaun	2100-2300	940	30.60	1.20	-
Q. floribunda	(10) Maheshkhan, Kumaun	-	1300	39.41	-	-
Q. floribunda	(11) Pauri Garhwal	-	220-640	23.53-43.24	-	-
Q. floribunda	(3) Kumaun	2038-2400	320-1960	37-95	-	-
Quercus leucotrichophora	(1) Mandal-Chopta, Chamoli Garhwal	1500-1650	990	35.08	2.43	0.253
Q. leucotrichophora	(12) Shitlakhet, Almora Kumaun	1800-2000	1920	12.67	2.43	0.25
Q. leucotrichophora	(5) Kumaun	1300-2600	430	-	-	-
Q. leucotrichophora	(13) Sarju catchment, Kumaun	1600	580	43.70	-	-
Q. leucotrichophora	(14) Mussorie, Dehradun Garhwal	1000-2050	580	22.43	1.68	0.34
Q. leucotrichophora	(15) Kumaun	1200-2300	741	40.90	-	-
Q. leucotrichophora	(16) Kumaun	1600	-	36.43	-	-
Q. leucotrichophora	(3) Kumaun	1700-2100	320-1560	12.00-74.00	-	-
Q. leucotrichophora	(17) Pranmati, Chamoli Garhwal	Montane	554	39.20	-	-
Q. leucotrichophora	(17) Kumaun	Montane	600-617	32.70-35.10	-	-
Q. leucotrichophora	(9) Mandal, Chamoli Garhwal	-	340	25.00	-	-
Q. leucotrichophora	(18) Pauri Garhwal	-	790-1260	13.60-71.25	-	-
Q. leucotrichophora	(19) Chambhi, Nainital, Kumaun	-	416	32.71	-	-
Q. leucotrichophora	(10) Maheshkhan, Kumaun	-	940	53.02	-	-
Q. leucotrichophora	(11) Mandal-Chopta, Chamoli Garhwal	-	100-860	8.42-59.71	-	-
Q. leucotrichophora	(20) Pauri Garhwal	-	150-730	6.67-43.96	-	-
Q. leucotrichophora	(21) Kailkhan, Kumaun	-	-	35.57	-	-
Q. leucotrichophora-mixed broadleaf	(7) Gagar, Kumaun	1900-2100	440	14.00	2.50	-
Quercus spp.	(9) Chamoli Garhwal	1400-2600	319-755	42.40-66.12	1.86-2.73	0.17-0.30
Quercusspp. - mixed coniferous	(20) Kewars area, Pauri Garhwal	1600-2100	-	-	1.33-2.02	0.27-0.45
Quercus-Cupressus torulosa	(7) Nainapeak, Kumaun	2100-2300	510	90.00	2.00	-
Rhododendron arboreum	(20) Pauri Garhwal	-	70-380	4.17-11.16	-	-
R. arboreum	(11) Mandal-Chopta, Chamoli Garhwal	-	130-830	6.25-58.88	-	-
R. arboreum-mixed broadleaf	(3) Kumaun	2100-2850	440-1180	18.00-123.00	-	-

Source: 1= Present Study, 2= Pande *et al*. (2002), 3= Singh *et al*. (1994), 4= Prakash and Uniyal (1999), 5= Ram *et al*. (2004), 6= Khera *et al*.(2001), 7= Kumar and Ram (2005), 8= Baduni and Sharma (1999), 9= Ghildiyal *et al*. (1998), 10= Saxena and Singh (1982), 11= Sharma *et al*. (2001), 12= Pandey (2003), 13= Rawal and Pangtey (1994), 14= Sanjeev *et al*. (2006), 15= Singh and Singh (1986), 16= Usman *et al*.(2000), 17= Thadani and Ashton (1995), 18= Kusumlata and Bisht (1991), 19= Ralhan *et al*. (1982), 20= Srivastava *et al*. (2005), 21= Tiwari (1982).

Tripathi et al. (2004) from 1.54 to 5.1 for tree layer of Saddle Peak forest (Andaman Island), Sharma et al. (1999) from 1.11 to 2.4 for tree layer and from 1.43 to 3.86 for shrub layer of Trikuta Hills (Jammu) and Pande et al. (2002) from 1.25 to 6.00 for shrub layer and 1.00 to 3.80 for herb layer of Chakrata forest (Dehradun, Garhwal). Most of the forest types in all the three vegetation layers showed high values of β-Diversity (>3.0). These high values of β-Diversity show high level of inter-habitat diversity along the topographic gradient.

Along the altitude, the geographic and climatic conditions change sharply (Kharkwal et al., 2005). The upper limit of species richness remains high up to a considerable altitudinal level (2500 m asl) and tree richness increases with increasing moisture in the Indian Central Himalaya (Rikhari et al., 1989). Difference in insolation period may occur according to altitude, thereby forming a range of microclimates in multifaceted landscapes. Total species richness (herbs+shrubs+trees) was maximum (58) in FT2 (between 2150 and 2400 masl) and FT3 (between 1900 and 2150 masl). In the temperate forests of Kumaun Himalaya, Kumar and Ram (2005) also recorded maximum species richness mixed broad-leaved forests. According to Champion and Seth (1968) more than 60 % plant species are generally present at middle altitudes, where the temperature covers a range from 10 °C to 24 °C. At lower altitude between 1500 and 1650 masl maximum G in herb and shrub layers was recorded with combined G of 28.54 m^2ha^{-1}, which was due to dominance of exotic invasive species Eupatorium adenophorum. It was the dominant shrub species at lower elevations below 2150 masl, which is giving strong competition to native ground vegetation.

The dominance-diversity (d-d) curves are based on the assumption that there is some correspondence between the share of community's resource a species utilizes and the share of community's niche space it occupies (Whittaker, 1975). Minor differences in d-d curves reflect the importance of each species in community. As illustrated in Fig. 3a, because of high IVI value *Q. leucotrichophora* in FT5 occupied top position on d-d curve. Because of this reason FT5 growing at lower elevation (1500 to 1650 masl) showed geometric curve. Shrub layers of FT1 and FT2 showed geometric d-d curves (Fig. 3b). This is because of high IVI values showed by few species in each of the forest types. *Rubus ellipticus* and *T. spathiflora* in FT1; and *S. kunthianus* and *T. spathiflora* in FT2, occupied top positions on respective d-d curves. Herb strata of FT1 growing at upper elevations (2100 to 2500 masl) showed geometric d-d curve (Fig. 3c). *Fragaria nubicola* and *Galium asperifolium* were dominant species present on top left position of d-d curve of FT1. In these forest types d-d curves showed that generally one or two species in the vegetation exploited major share of resources. Dominance-diversity curves in these forest types showed the geometric series, which

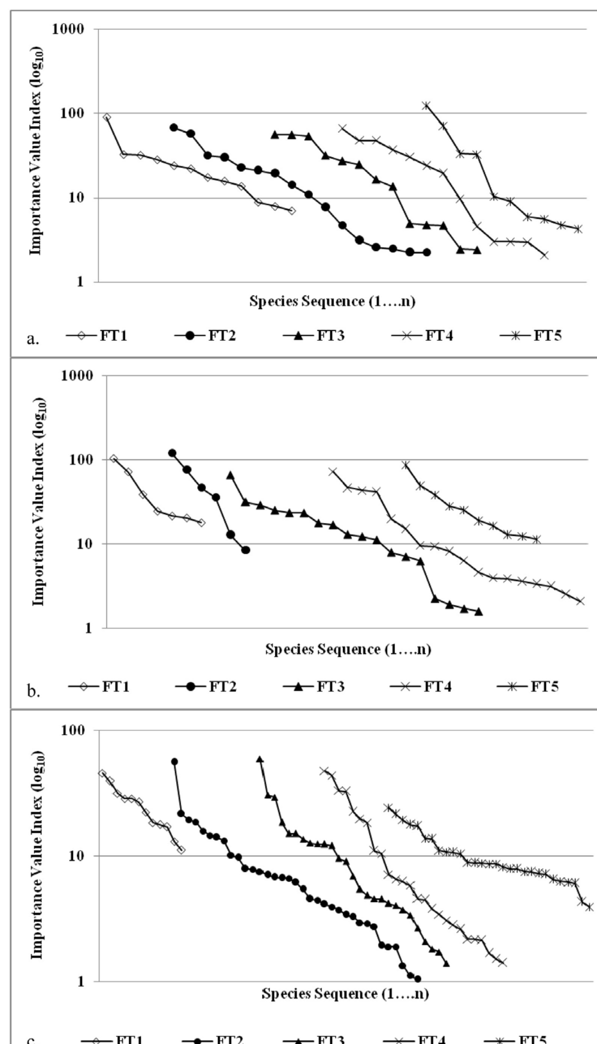

Fig. 3. Dominance-diversity curves
a. Tree strata, b. shrub strata, c. herb strata.

confirms the niche pre-emption hypothesis of Whittaker (1975). Geometric series is indicative of lower diversity and is often shown by vascular plant communities with low diversities (Whittaker, 1972). The geometric series is predicted to occur in a situation, where species arrived to unsaturated habitat at regular time intervals to occupy the fractions of remaining hyperspace. It is indicative of low competition among the species, because IVI values of species are proportional to the amount of the resource they utilize. Hence the most dominant species always utilize the maximum niche space and resources within the communities. Low $\overline{H}$ and high Cd values in these forest types in these vegetation layers (Tables 5) also confirmed findings of the d-d curves.

The log series indicates that moderately common species reflect most closely the nature of the environment, and abundant species fluctuate less violently from time to time. Tree layer of FT1 growing at upper elevation (2100 to 2500 masl) showed log curve, where *A. pindrow* dominated the community, followed by Persea duthiei, *A. indica* and *Q. floribunda*. Whereas shrub layers of FT3 and FT5 growing at lower elevations (1500 to 2150 masl) showed log curve. *Thamnocalamus falconeri*, *R. ellipticus* and *Sarcococca saligna* in FT3; *Sinarundinaria falcata*, *Berberis asiatica*, *Eupatorium adenophorum* and *Rubus nepalensis* in FT4; and *E. adenophorum*, *Berberis asiatica*, *S. falcata* and *Hedera nepalensis* in FT5 were present at top left of the respective d-d curves. A log series result, if the interval between the arrivals of the species was random rather than regular (Boswell and Patil, 1971). It is found in the situations where one or few factors dominate the ecology of the community.

In the lognormal distribution, the large numbers of factors determine the number of species in a community. Lognormal series represent high diversity condition. Tree layers of FT2 to FT4 showed lognormal distribution. *Persea duthiei*, *Q. floribunda*, *L. ovalifolia* and *R. arboreum* in FT2; *Q. leucotrichophora*, *P. duthiei*, *D. himalense* and *B. alnoides* in FT3; and *D. himalense*, *B. alnoides*, *Q. leucotrichophora* and *P. odoratissima* in FT4, were dominant species present at top left portions of the respective d-d curves. Herb layers of FT2 to FT5 showed lognormal distribution. *Fragaria nubicola*, *Lecanthus peduncularis* and *Paris polyphylla* in FT2; *F. nubicola*, *L. peduncularis*, *Viola pilosa* and *Scutellaria scandens* in FT3; *F. nubicola*, *Galium asperifolium*, *L. peduncularis*, *Stellaria media* and *S. scandens* in FT4; and *F. nubicola*, *Origanum vulgare*, *Oxalis corniculata* and *Taraxacum officinale* in FT5 were dominant species present at top left portions of the d-d curves. The lognormal series describes the partitioning of realized niche space among various species and it is the consequence of the evolution of diversity in the species along the niche parameters that they exploit.

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LITERATURE CITED

Baduni, N.P. and C.M. Sharma. 1997. Flexibility fitness compromise in some moist temperate forests of Garhwal Himalaya. Ann. For. 5: 126- 135.

Baduni, N.P. and C.M. Sharma. 1999. Community structure and growing stock variation in *Quercus floribunda* forest on different aspects of Garhwal Himalaya. Bangladesh J. For. Sci. 28(2): 82-93.

Baduni, N.P. 1996. Growing stock variation in different forest cover types of Pauri Garhwal. D.Phil. Thesis, HNB Garhwal University, Srinagar (Garhwal), Uttarakhand, India.

Boswell, M.T. and G.P. Patil. 1971. Chance mechanisms generating the logarithmic series distribution used in the analysis of numbers of species and individuals. In: Statistical Ecology, Patil, G.P., Pielou, E.C., Wates, W.E. (eds.), Penn State University Press, Philadelphia, P.A. pp99-130.

Champion, H.G. and S.K. Seth. 1968. A Revised Survey of the Forest Types of India. Government of India Publications, New Delhi.

Curtis, J.T. and R.P. McIntosh. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31(3): 434-55.

Dhar, U., Rawal, R.S. and S.S. Samant. 1997. Structural diversity and representativeness of forest vegetation in a protected area of Kumaun Himalaya, India: implications for conservation. Biodivers.

Conserv. 6(8): 1045-1062.
Gairola, S., Sharma, C.M., Rana, C.S., Ghildiyal, S.K. and S. Suyal. 2010. Phytodiversity (Angiosperms and Gymnosperms) in Mandal-Chopta forest of Garhwal Himalaya, Uttarakhand, India. Nature Science 8(1): 1-17.
Gairola, S. 2010. Phytodiversity, forest composition, growing stock variation and regeneration status in the Mandal-Chopta forest of Garhwal Himalaya. D.Phil. thesis submitted to HNB Garhwal Central University, Srinagar Garhwal, Uttarakhand, India.
Ghildiyal, S., Baduni, N.P., Khanduri, V.P. and C.M. Sharma. 1998. Community structure and composition of Oak forests along altitudinal gradient in Garhwal Himalaya. Indian J. For. 21(3): 242-247.
Kent, M. and P. Coker. 1992. Vegetation description and Analysis, Belhaven Press, London.
Kharakwal, G., Mehrortra, P., Rawat, Y.S. and Y.P.S. Pangtey. 2005. Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. Curr. Sci. 89(5): 873-878.
Khera, N., Kumar, A., Ram, J. and A Tewari. 2001. Plant biodiversity assessment in relation to disturbances in mid-elevational forest of Central Himalaya, India. Trop. Ecol. 42(1): 83-95.
Kumar, A. and J. Ram. 2005. Anthropogenic disturbances and plant biodiversity in forest of Uttaranchal, Central Himalaya. Biodivers. Conserv. 14: 309-331.
Kusumlata and N.S. Bisht. 1991. Quantitative analysis and regeneration potential of moist temperate forest in Garhwal Himalaya. Indian J. For. 14(2): 98-106.
Margalef, D.R. 1958. Information theory in ecology. Gen. Syst. 3: 36-71.
Mishra, A., Sharma, C.M., Sharma, S.D. and N.P. Baduni. 2000. Effect of aspect on the structure of vegetation community of moist Bhavar and Tarai Shorea robusta forest in Central Himalaya. Indian For. 126(6): 634-642.
Nayak, A.K., Purohit, R.P and R.K. Thapliyal. 1991. Phytosociological analysis of some temperate forests of Chamoli (Garhwal). In: Advances in Himalayan Ecology. Rajwar, G.S. (ed.), Today and Tomorrow's Printers and Publishers, New Delhi. pp85-111.
Negi, C.S. and S. Nautiyal. 2005. Phyto-sociological studies of a traditional reserve forest - Thal Ke Dhar, Pithoragarh, Central Himalayas (India). Indian For. 131(4): 519-532.
Pande, P.K., Negi, J.D.S. and S.C. Sharma. 2002. Plant species diversity, composition, gradient analysis and regeneration behaviour of some tree species in a moist temperate western Himalayan forest ecosystem. Indian For. 128(8): 869-886.
Pandey, J.C. 2003. Vegetation analysis in a mixed Oak-Conifer forest of Central Himalaya. Indian J. For. 26(1): 66-74.
Pant, S.C. 1987. Vegetation litter fall and litter decomposition and ground vegetation production on the North- West and South-West facing slopes in forest at Gopeshwar. Garhwal Himalaya. D.Phil. Thesis, HNB Garhwal University, Srinagar (Garhwal), Uttarakhand, India.
Phillips, E.A. 1959. Methods of Vegetation study. New York: Henry Holt and Co. Inc. 107.
Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13: 131-144.
Prakash, C. and V.K. Uniyal. 1999. Structure of forest vegetation along an altitudinal gradient in the Valley of Flowers National Park and its vicinity, Western Himalaya. Ann. For. 7(1): 60-69.
Putman, R.J. 1994. Community Ecology. Chapman and Hall, London.
Ralhan, P.K., Saxena, A.K. and J.S. Singh. 1982. Analysis of forest vegetation at and around Nainital in Kumaun Himalaya. Proc. Indian Nat. Sci. Acad. B 48(1): 121-137.
Ram, J., Kumar, A. and J. Bhatt. 2004. Plant diversity in six forest types of Uttaranchal, Central Himalaya, India. Curr. Sci. 86(7): 975-978.
Rawal, R.S. and Y.P.S. Pangtey. 1994. High altitude forests in a part of Kumaun, Central Himalaya. Proc. Indian Nat. Sci. Acad. B 60: 557-564.
Rikhari, H.C., Chandra, R. and S.P. Singh. 1989. Pattern of species distribution and community characters along a moisture gradient within an oak zone of Kumaun Himalaya. Proc. Indian Nat. Sci. Acad. 55(B): 431-438.
Sanjeev, Gera, M. and P.L. Sankhayan. 2006. Phytosociological analysis of Arnigad micro-watershed in Mussorie hills of Garhwal Himalayas. Indian For. 132(1): 19-29.
Saxena, A.K. and J.S. Singh. 1982. A Phytosociological analysis of woody species in forest communities of a part of the Kumaun Himalaya. Vegetatio 50: 3-22.
Saxena, A.K., Pandey, U. and J.S. Singh. 1978. On the ecology of Oak forest in Nainital hills, Kumaun Himalaya. In: Glimpses of Ecology. Singh, J.S. and Gopal, B. (eds.), Prof. R. Mishra Commemoration Volume. Jaipur International Scientific Publication, pp167-180.
Shannon, C.E. and W. Weaver. 1963. The mathematical theory of communication. Urbana, USA: University of Illinois Press, p117.
Sharma, C.M., Ghildiyal, S.K., Gairola, S. and S, Suyal. 2009c. Vegetation structure, composition and diversity in relation to the soil characteristics of temperate mixed broad-leaved forest along an altitudinal gradient in Garhwal Himalaya. Indian J. Sci. Tech. 2(7): 39-45.
Sharma, C.M., Baduni, N.P., Gairola, S., Ghildiyal, S.K. and S. Suyal. 2010b. The effect of slope aspects on the forest composition, community structure and soil nutrient status of some major natural temperate forest types of Garhwal Himalaya. J. Forestry Res. 21(3): 331-337, doi: 10.1007/s11676-010-0079-y.
Sharma, C.M., Baduni, N.P., Gairola, S., Ghildiyal, S.K. and S. Suyal. 2010c. Variation in biomass and carbon stocks of some major natural forest types of Garhwal Himalaya, India. For. Ecol. Manage. 260(12): 2170-2179. doi: 10.1016/j.foreco.2010.09.014.
Sharma, C.M. and N.P. Baduni. 2000. Effect of aspects on the structure of some natural stands of *Abies pindrow* in Himalayan moist temperate forest. Environmentalist 20(4): 309-317.
Sharma, C.M., Gairola, S., Ghildiyal, S.K. and S. Suyal. 2010d. Physical Properties of Soils in Relation to Forest Composition in Moist Temperate Valley Slopes of the Central Western

Himalaya. J. Forest Sci. 26(2): 117-129.

Sharma, C.M., Gairola, S., Ghildiyal, S.K. and S. Suyal. 2009b. Forest dependent livelihood in relation to socio-economic status of the people in temperate villages of Garhwal Himalaya: A case study. Mt. Res. Develop. 29(4): 308-319. doi: 10.1659/mrd.00018.

Sharma, C.M., Khanduri, V.P. and S. Goshwami. 2001. Community composition and population structure in temperate mixed broad-leaved and coniferous forest along an altitudinal gradient in a part of Garhwal Himalaya. J. Hill Res. 14(1): 32-43.

Sharma, C.M., Kohli, S. and V.P. Khanduri. 1999. Structural composition of mixed broadleaved-coniferous forest along an altitudinal gradient in Trikuta hills of Jammu province of the Western Himalaya. J. Hill Res. 12(2): 107-113.

Sharma, C.M., Suyal, S., Gairola, S. and S.K. Ghildiyal. 2009a. Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. J. Am. Sci. 5(5): 119-128

Sharma, C.M., Suyal, S., Gairola, S. and S.K. Ghildiyal. 2010a. Role of Physiographic factors in distribution of *Abies pindrow* (Silver Fir) along an altitudinal gradient in Himalayan temperate Forests. Environmentalist 30(1): 76-84, doi: 10.1007/s10669-009-9245-1.

Simpson, E.H. 1949. Measurement of diversity. Nature 163: 688.

Singh, J.S. and S.P. Singh. 1986. Structure and function of central Himalaya oak forests. Proc. Indian Nat. Acad. 96: 156-189.

Singh, S.P., Adhikari, B.S. and D.B. Zobel. 1994. Biomass productivity, leaf longevity and forest structure in the Central Himalaya. Ecol. Mono. 64: 401-421.

Slobodkin, L.B. and H.L. Sanders. 1969. On the contribution of environmental predictability to species diversity. Brookhaven Symp. Biol. 22: 82-95.

Srivastava, R.K., Khanduri, V.P., Sharma, C.M. and P. Kumar. 2005. Structure, diversity and regeneration potential of Oak dominant conifer mixed forest along an altitudinal gradient in Garhwal Himalaya. Indian For. 131(12): 1537-1553.

TerBraak, C.J.F. 1987. The analysis of vegetation environmental relationship by canonical correspondence analysis. Vegetatio 69: 69-77.

Thadani, R. and P.M.S. Ashton. 1995. Regeneration of banj oak (*Quercus leucotrichophora* A. Camus) in the central Himalaya. For. Ecol. Manage. 78: 217-224.

Tiwari, J.C. and S.P. Singh. 1985. Analysis of woody vegetation in a mixed oak forest of Kumaun Himalaya. Proc. Indian Nat. Sci. Acad. B 51: 232-247.

Tiwari, J.C. 1982. Vegetational analysis along altitudinal gradient around Nainital. Ph.D. Thesis, Kumaun University, Nainital, Uttarakhand, India.

Tripathi, K.P., Tripathi, S., Selven, T., Kumar, K., Singh, K.K., Mehrotra, S. and P. Pushpangadan. 2004. Community structure and species diversity of Saddle Peak forests in Andaman Island. Trop. Ecol. 45(2): 241-250.

Usman, S., Singh, S.P., Rawat, Y.S. and S.S. Bargali. 2000. Fine root decomposition and nitrogen mineralisation patterns in *Quercus leucotrichophora* and Pinus roxburghii forests in Central Himalaya. For. Ecol. Manage. 131: 191-199.

Whittaker, R.H. 1972. Evolution and measurement of species diversity. Taxon 21: 213-215.

Whittaker, R.H. 1975. Communities and Ecosystems. (2^{nd} Edn.). McMillan Publishing Company, New York.

Whittaker, R.H. 1977. Evolution of species diversity in land plant communities. Evol. Biol. 10: 1-67.

Wikum, D.A. and M.K. Wali. 1974. Analysis of North Dakota Gallery forest vegetation in relation to topographic and soil gradients. Ecol. Monogr. 44: 441-464.

Zobel, D.B., Mckee, A., Hawk, G.M. and C.T. Dyrness. 1976. Relationships of environment to the composition, structure and diversity of forest communities of the central western cascades of Oregon. Ecol. Monogr. 46(2): 135-156.

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